# SGsim: Co-simulation Framework for ICT-Enabled Power Distribution Grids

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**Abstract.** Empowering power grids with ICT is fundamental for the future power grid. Simulation plays an essential role for evaluating emerging smart grid applications. The presented co-simulation framework SGsim is based on two main simulators, OMNeT++ and OpenDSS. With newly added components, smart grid applications in the electricity distribution network can now be investigated and evaluated. Conservation Voltage Reduction (CVR) is a mechanism to reduce the power demand which eventually will reduce the energy consumption. In a case study, the co-simulation framework is used to explore the potential energy saving by applying a closed-loop CVR inside a residential power grid.

**Keywords:** Smart grid · Co-simulation · Electricity distribution network · Communication system · Conservation voltage reduction

## 1 Introduction

Smart grid presents a set of practices and technologies to run the power grid in an efficient, secure, reliable, sustainable and economic way. Information and Communication Technology (ICT) can contribute most to optimizing the operation of the future power grid. Applications such as CVR or Volt/VAR optimization have the potential to reduce the power consumption especially during the peak hours. The rapidly increasing penetration of fluctuating renewable energy sources brings new challenges to the power grid, especially inside the distribution network. In addition to the loads and supplies, a distribution grid contains also components such as transformers, capacitor banks and energy storage elements. Connecting these components together through a data communication network is very crucial. It will make it possible to operate the power grid in an optimal way. Moreover, it will be possible to react very fast to emergency conditions. SGsim [1] is a co-simulation framework for the design and analysis of such systems. We are planning to provide the framework as open source for the education and research community.

## 2 Description of SGsim

The co-simulation framework SGsim is based on two main simulators: OpenDSS [3] and OMNeT++ [5]. In addition to a stand-alone executable program,


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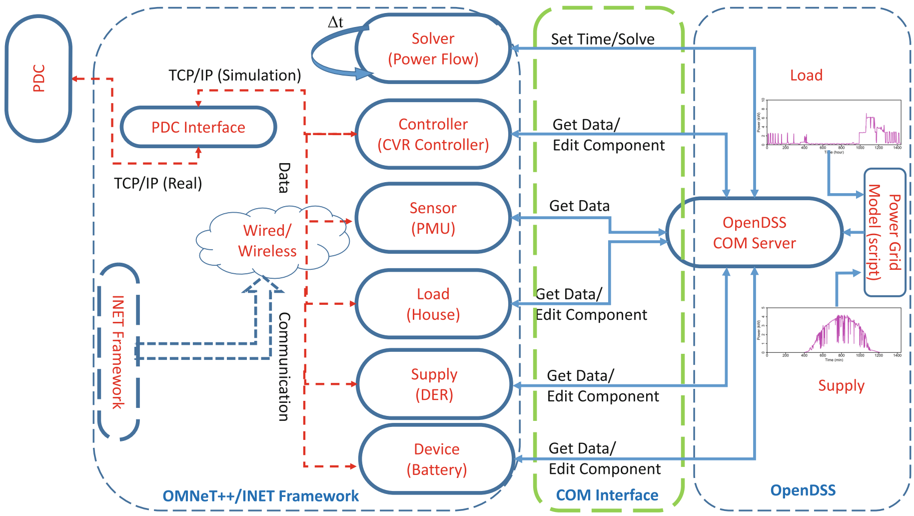


**Fig. 1.** Structure of the co-simulation framework with the connections between the different components

OpenDSS provides an in-process Component Object Model (COM) server DLL designed to be driven from an external program. OMNeT++ is mainly a data communication simulator. Additionally several frameworks, such as the INET framework, have been developed with well-tuned data communication components such as TCP/IP, 802.11 and Ethernet. In order to enable the use of the framework in the field of smart grid applications, we have integrated new components for the electricity distribution network. Figure 1 shows the different components of the simulator. Through the COM interface, it is possible to control the execution of the circuit and to change/add/remove different components. This is very helpful when simulating time-dependent scenarios. The main components of the simulator are:

- Power Grid Model: The OpenDSS is fed with the a script that describes the different components of the power grid and the interconnections. Furthermore, time-dependent loads and supplies can be provided as text files. For household demand and photovoltaic supply real data from Pecan Street [4] will be used. This database provides an 1-min resolution aggregated power usage signal as well as power consumption of individual devices. This can be very suitable in exploring applications such as Demand Response (DR).
- Solver: It controls the OpenDSS execution through the COM interface. It ensures time synchronization between the OpenDSS and OMNeT++.
- Load: It is the OMNeT++ component of the load in the power grid, e.g., a house. It can measure power grid parameters such as voltage, current and power at a specific time through the COM interface. It is also possible to change load parameters, e.g., running time for DR applications.

- Supply: It represents a power generation unit in OMNeT++, e.g., Distributed Energy Resources (DER). It is also possible to change supply parameters, e.g., regulate the output power (active and reactive power).
- Device: It represents power grid devices (e.g., Battery, Switch, Capacitor bank, ...). Through the COM interface, it is possible to change the parameters, e.g., power factor.
- Sensor: It can only read data on a specific component (e.g., Bus, Load, DER) and send it to other components. For instance Phasor Measurement Unit (PMU) is considered as a sensor and it sends data to Phasor Data Concentrator (PDC) interface using simulated TCP/IP packets. The data is formatted using a standard (IEEE c37.118) so that the real PDC can interpret the packets.
- Controller: It represents an intelligent unit within the system. It receives data from other components and then, based on specific algorithms, it can adapt system parameters. For instance a CVR controller can change the voltage settings of Load Tap Changer (LTC) in order to change the voltage of the transformer.
- PDC interface: It receives simulated packets inside the simulator. It converts it to real TCP/IP packets and forwards them to real software components such as OpenPDC. In this case, the simulation should be run in real-time mode.

## 3 Case Study: Conservation Voltage Reduction (CVR)

CVR is a method used by utilities to reduce the power demand by decreasing voltage levels. The main idea is that some devices will consume less power when the actual voltage is lower than the designed voltage. An important aspect here is to insure that the voltage at the costumer side is within the standardized limits (e.g., in Germany $230 \pm 10\,\%$). In this case study we apply a closed-loop CVR inside neighborhood with 10 houses connected to a transformer. The closed-loop CVR uses feedback information, i.e. voltage at houses, to adapt the output voltage at the transformer. A CVR controller is installed near the transformer. The loads at the houses are modeled as ZIP loads with the parameters ($Z_P = 0.85, I_P = -1.12, P_P = 1.27$) [2]. Equation 1 gives the current power as a function of current voltage (V). The constants $P_0$ and $V_0$ are the design power and voltage respectively.

$$P = P_0 \left[ Z_p \left( \frac{V}{V_0} \right)^2 + I_p \left( \frac{V}{V_0} \right) + P_p \right] \tag{1}$$

The controller can change the voltage output of the transformer by sending an edit command through the COM interface. Edit commands are used to change the parameters of a specific component. Each house sends periodically data messages to the CVR controller. The messages contain the measured voltage at the load. Additionally, if the voltage exceeds specific limits, a warning

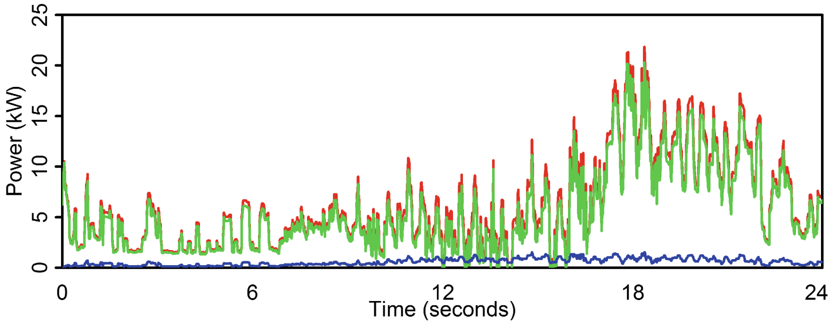


**Fig. 2.** Power consumed by the neighborhood with (green) and without (red) CVR and the difference (blue) (Color figure online).

message is sent to the controller which in turns reacts by changing the voltage at the transformer. Figure 2 shows the power flow through the transformer with and without applying CVR. The green and red curves show the power consumption with and without applying CVR, respectively. The blue curve, depicts the difference between the two curves. As it can be seen, the power reduction is higher when the load is high. The energy consumption without CVR is 145.7 kWh compared to 131.6 kWh when applying CVR. This represents a daily saving of about 14 kWh for the 10 houses. An important aim of CVR in addition to save energy is reducing the power demand, especially during the peak periods. In fact, CVR can provide Ancillary Services to the grid, i.e., provide regulation power to maintain balance of supply and demand and alleviate grid stress. This saves utility companies building addition power plants (i.e., additional spinning reserve). As can be seen in Fig. 2, at 6 PM, the power difference is about 2 kW. If we scale this value up to a city with thousands of houses, this would mean we can save building new several mega watts power plant.

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